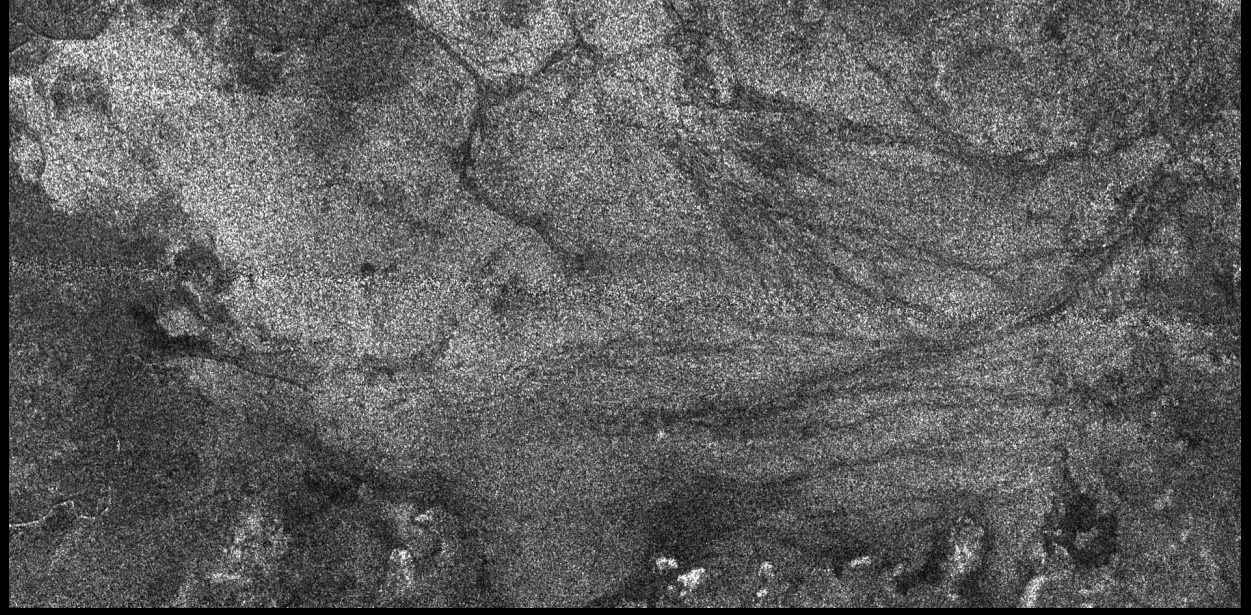
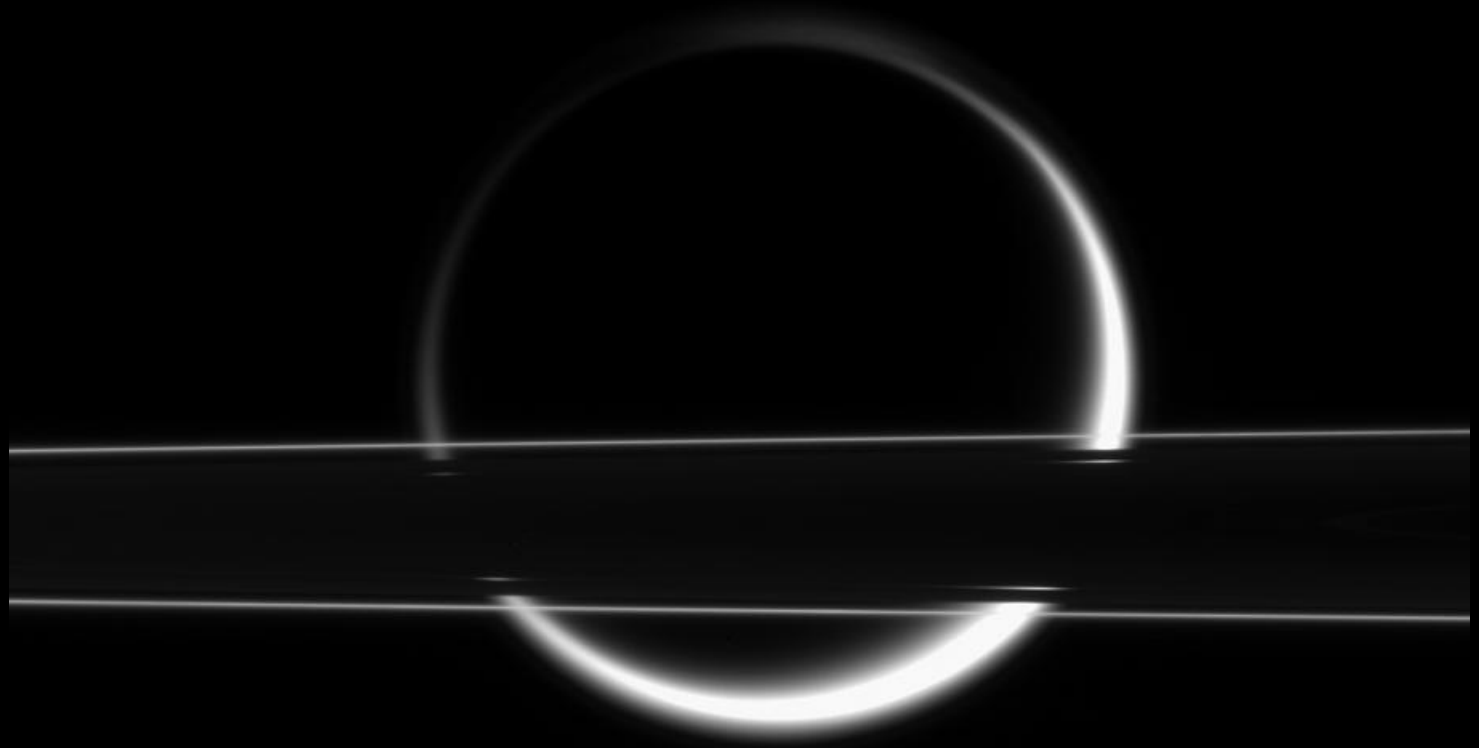


Not afraid to ride the wind: A Montgolfière for Titan

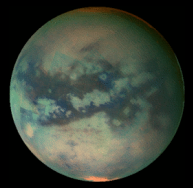
Jonathan I. Lunine
Kim Reh
John Elliott
Tom Spilker
Ralph Lorenz
and the TiPEx Team

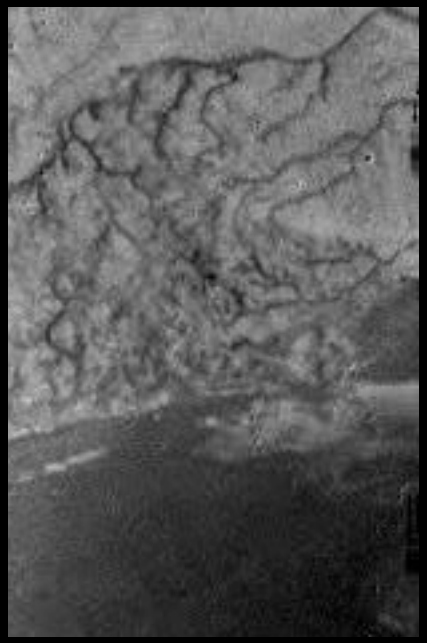

Ceres
952 km
Pluto
2,302 km
Triton
2,706 km
2003 UB313
3,000 km
Moon
3,474 km
Titan
5,150 km
Ganymede
5,262 km

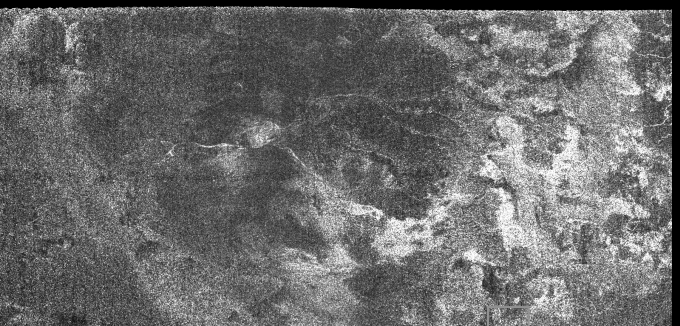
Titan is big….

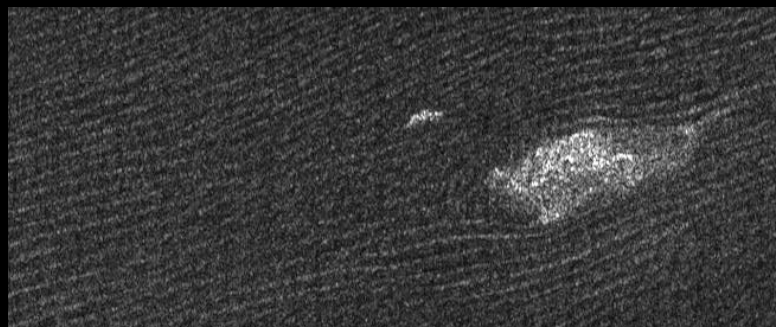


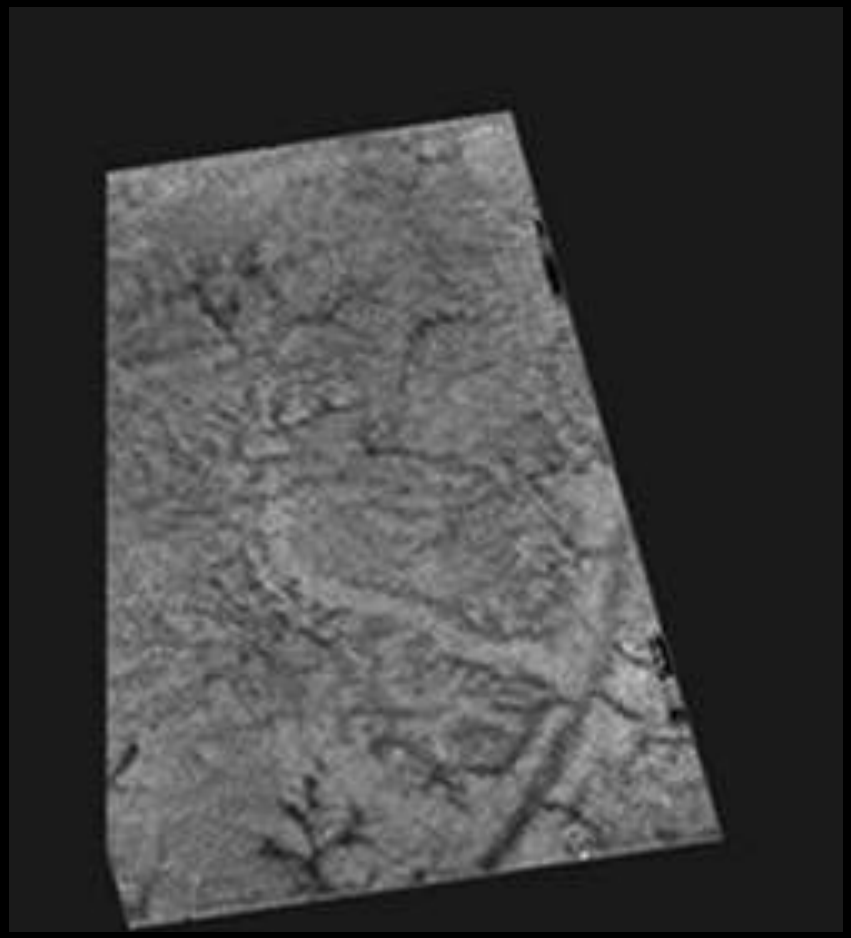
Titan’s atmosphere is dense, nitrogen-methane, cold…



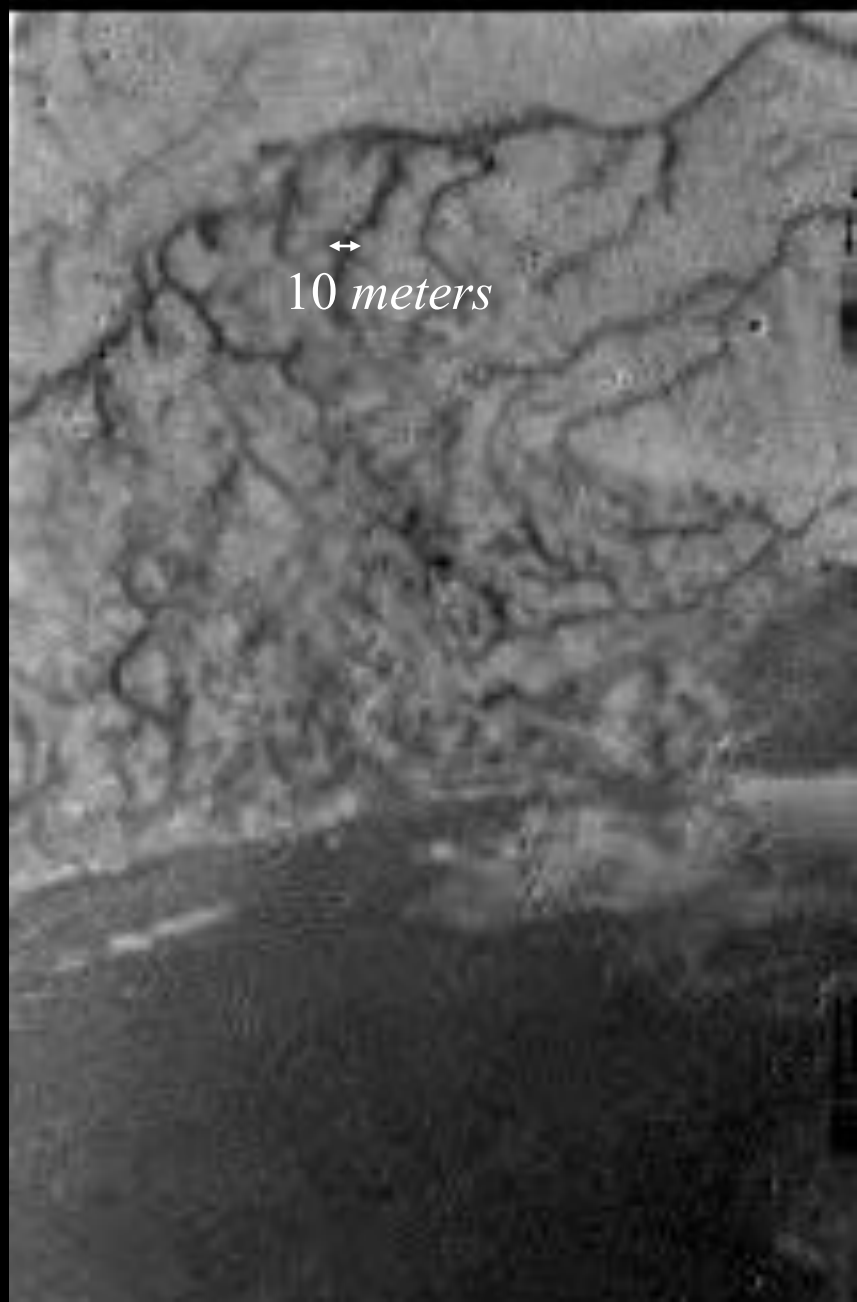




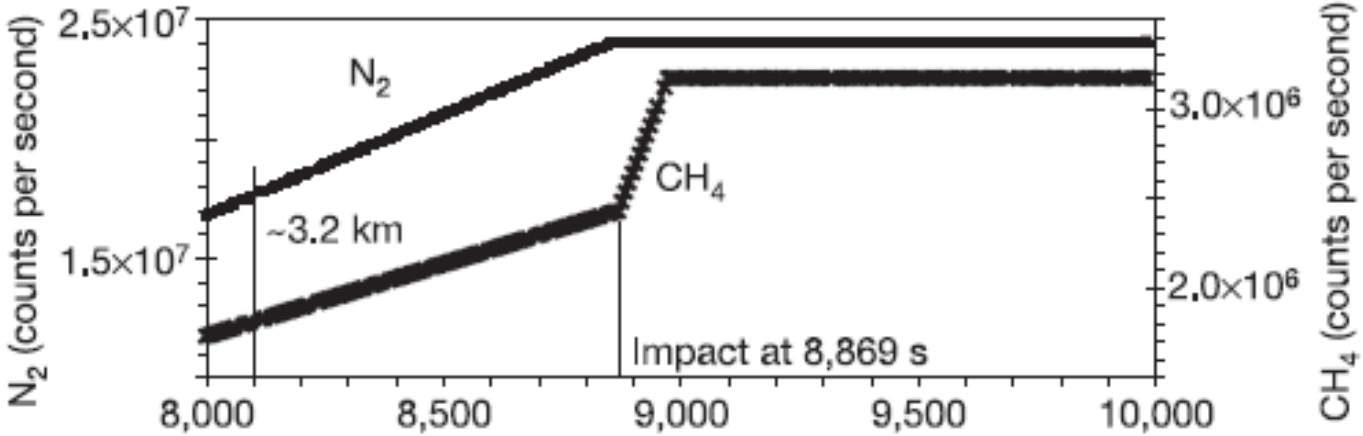


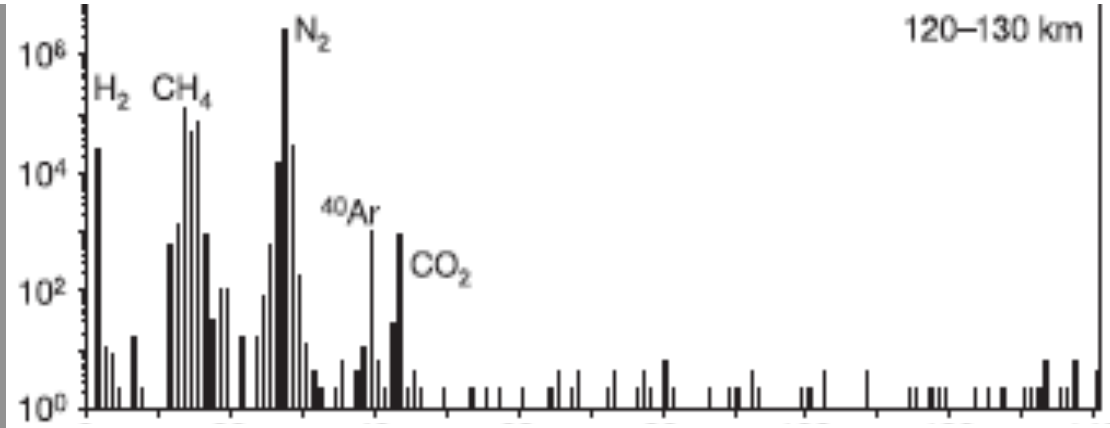


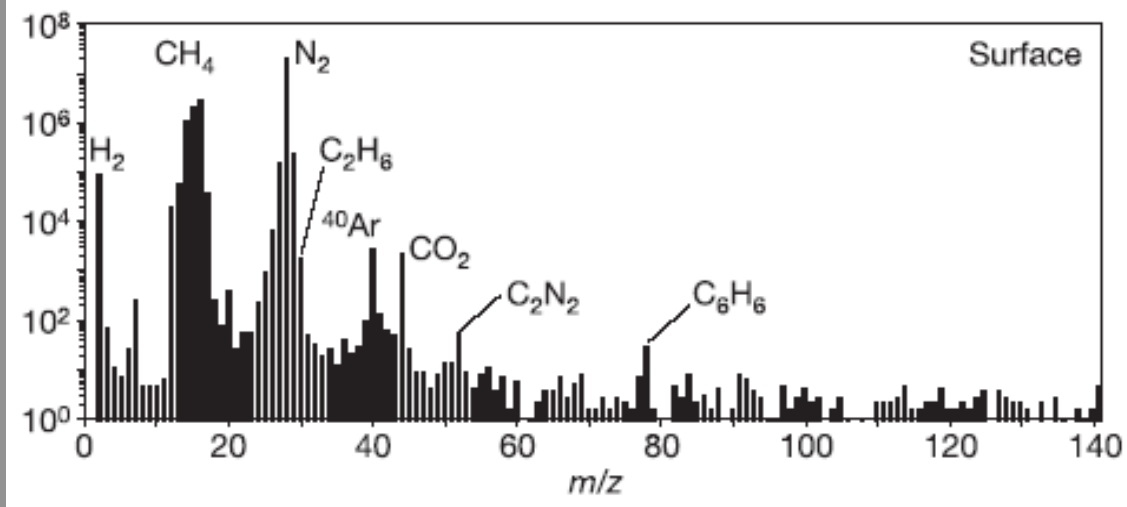
Rains and springs of methane carve channels and widen fractures in the water ice crust…

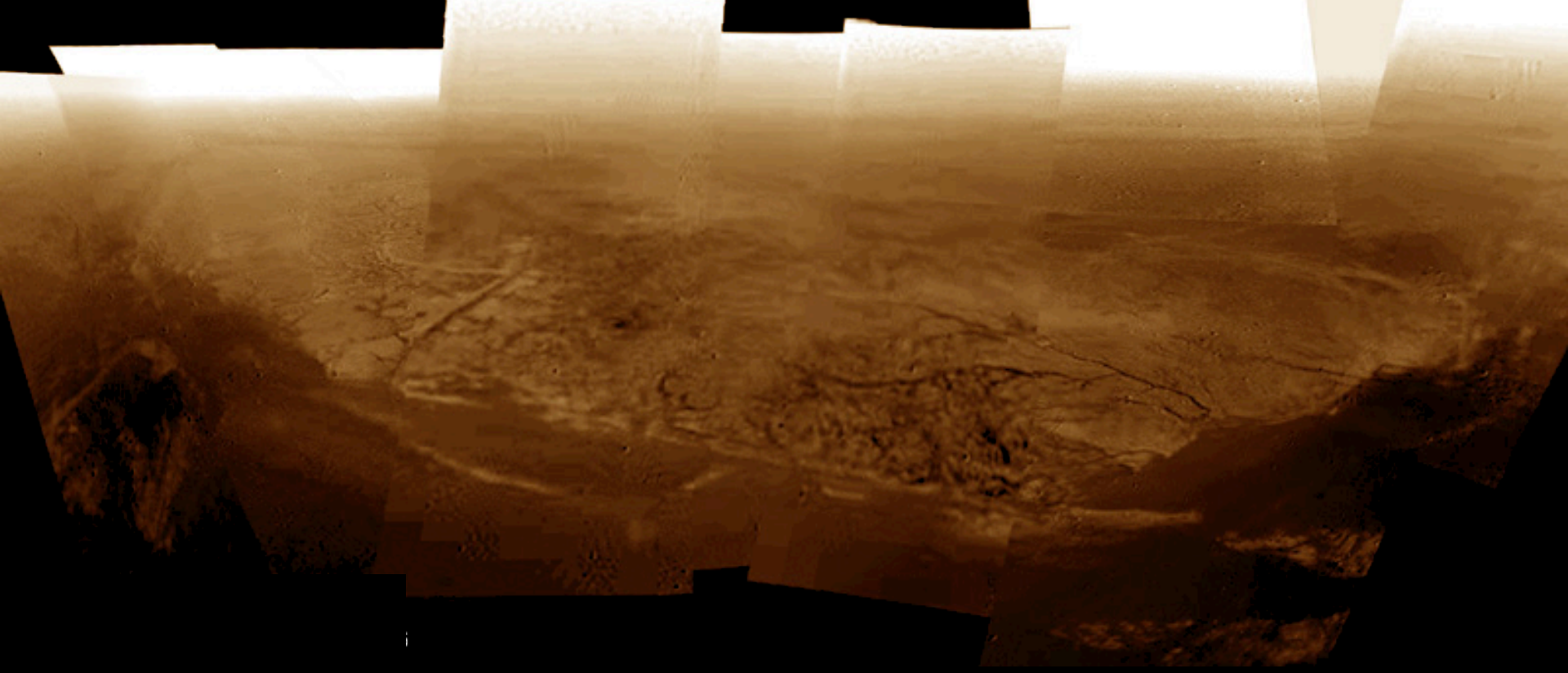


...and dump pebby debris
on surrounding plains


2.5×10^7
1.5×10^7
N2 (counts per second)
N2
CH4
~3.2 km
Impact at 8,869 s
3.0×10^6
2.0×10^6
CH4 (counts per second)
8,000
8,500
9,000
9,500
10,000

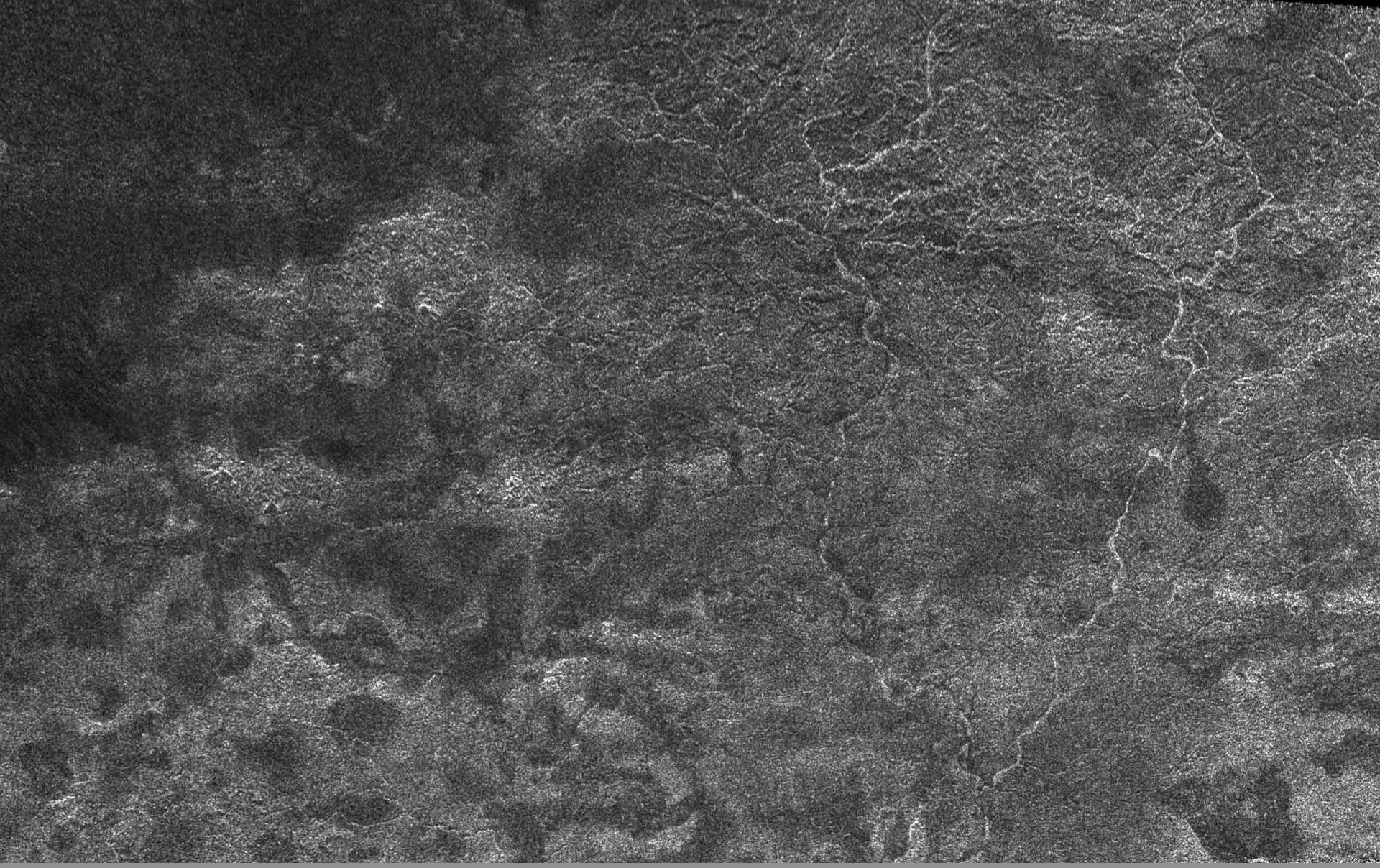

120–130 km
10^6
10^4
10^2
10^0
H2
CH4
N2
40Ar
CO2


Surface
10^8
10^6
10^4
10^2
10^0
H2
CH4
N2
C2H6
40Ar
CO2
C2N2
C6H6
0
20
40
60
80
100
120
140
m/z

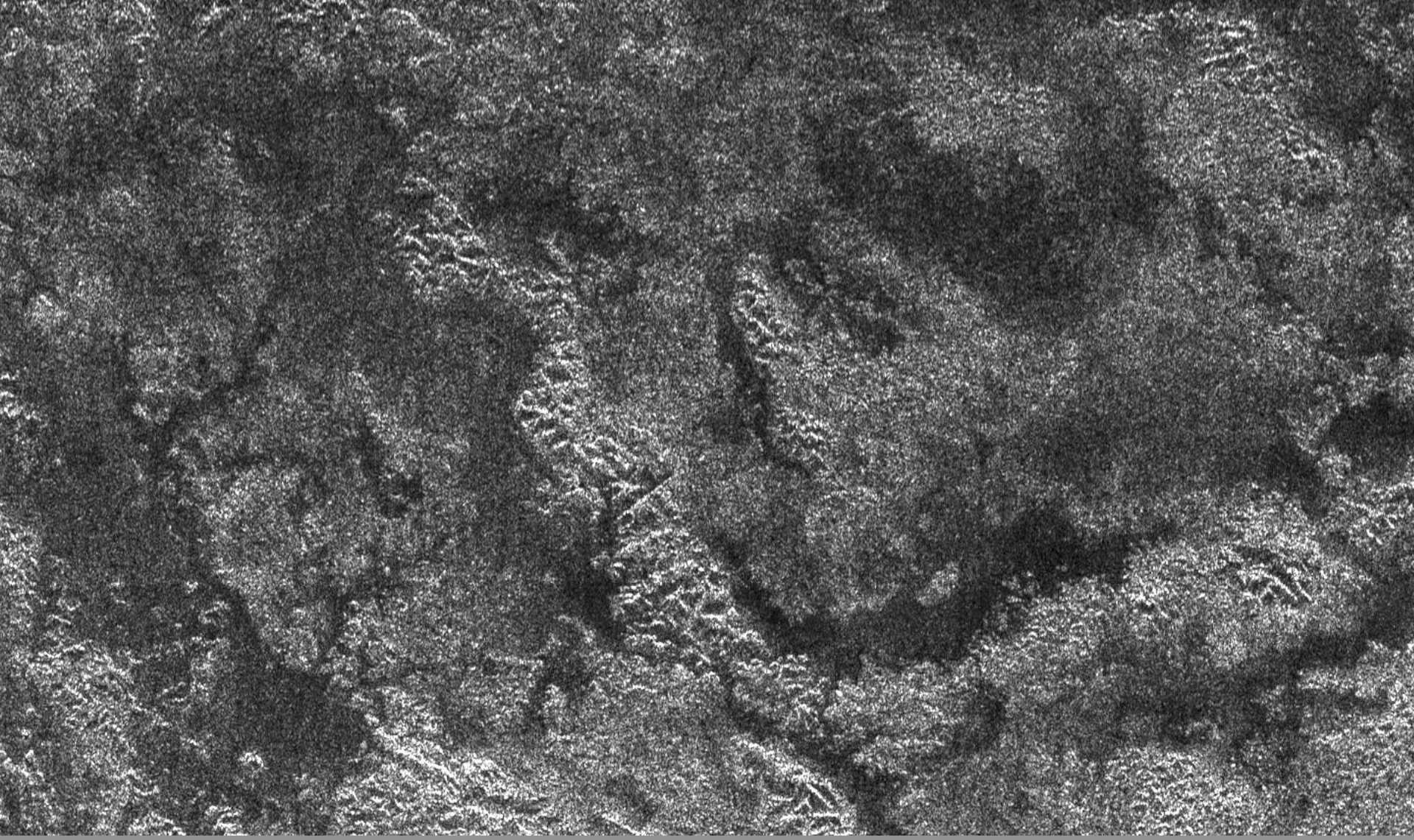


Titan has vistas that evoke—more than any other world beyond Earth—fantastical *lands* of the human imagination…

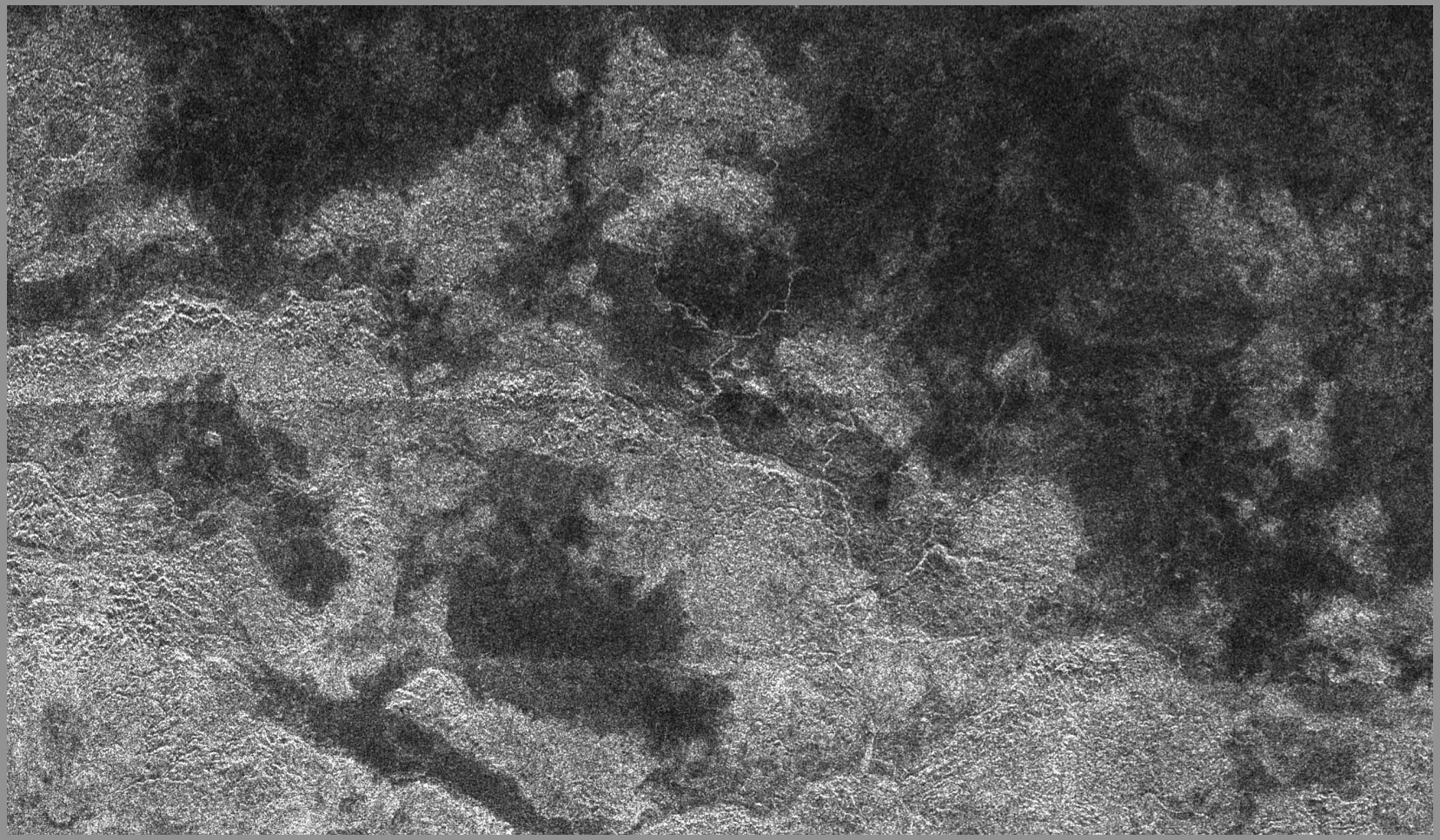
“In Xanadu did Kubla Khan
A stately pleasure-dome
decree:



…where Alph, the sacred river, ran…



…through caverns measureless to man…



…down to a sunless sea.”

Samuel Taylor Coleridge, *Xanadu*

“Titan is a complex world, which appears to be influenced by tectonic, fluvial and atmospheric processes, in many ways similar to Earth,”
Porco et al., Science, 2005.

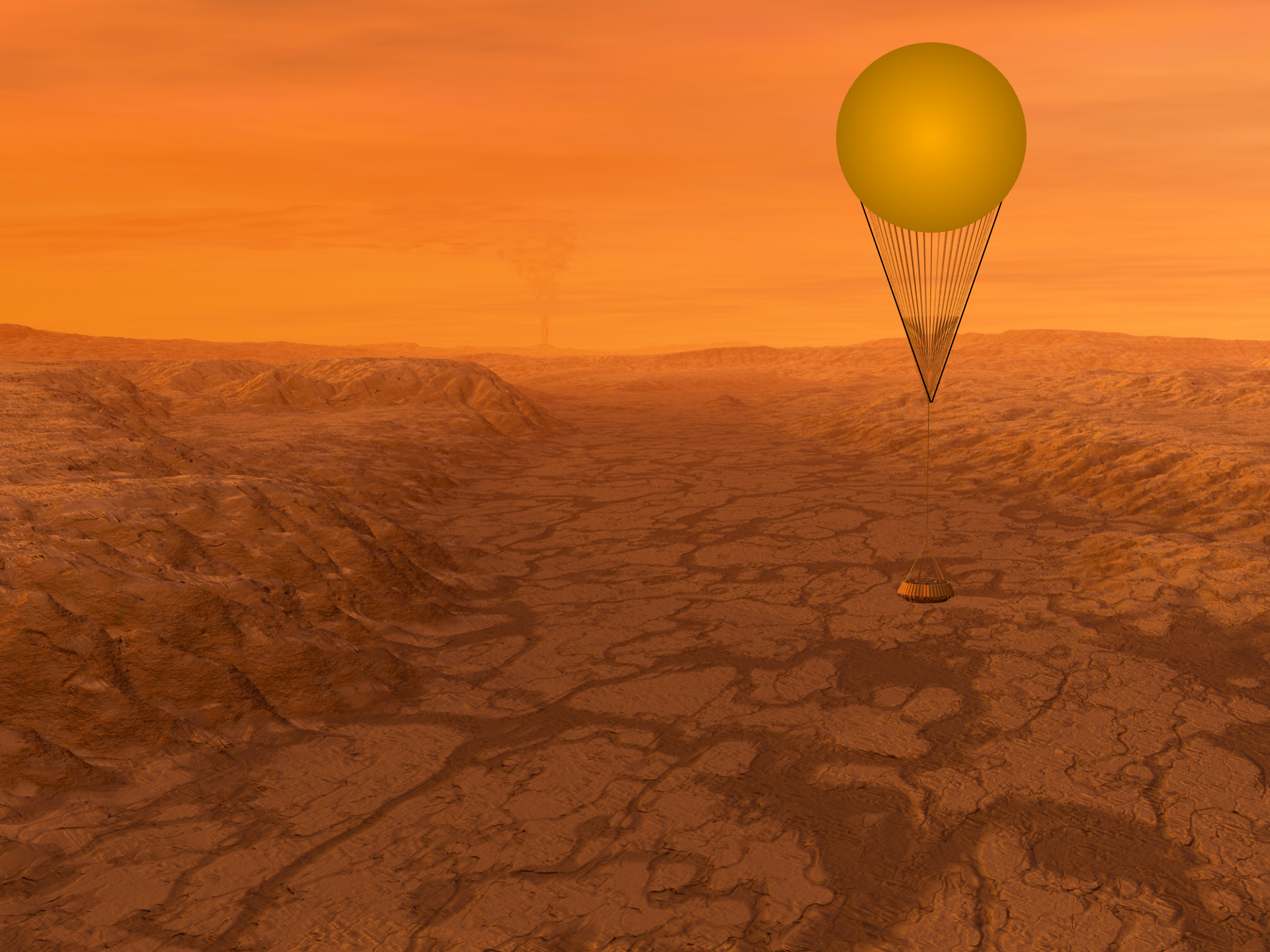
“As an environment, Titan certainly meets all of the stringent criteria outlined above for life.”
Steven Benner et al. Current Opinion in Chemical Biology, 2004

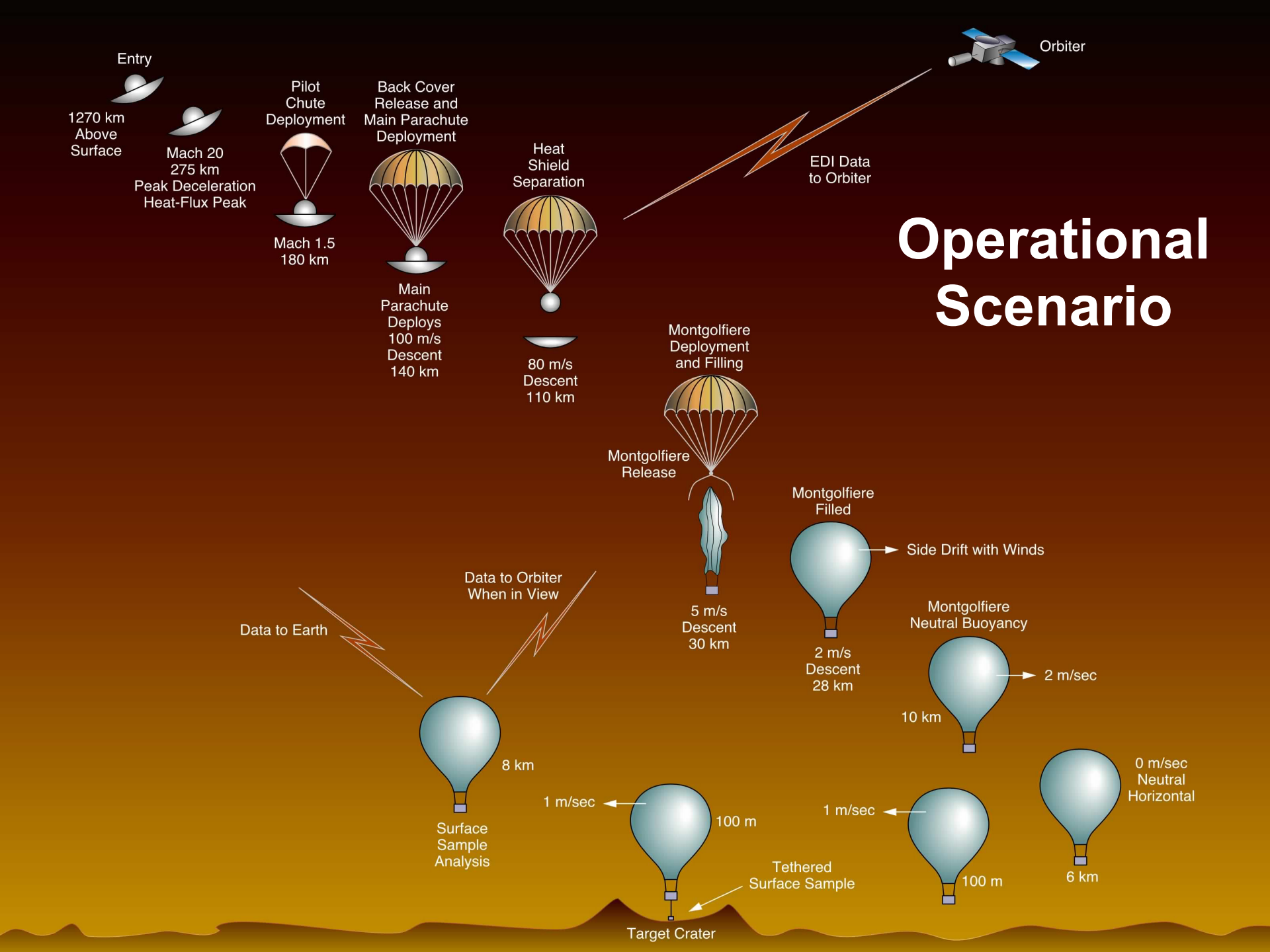
“Titan is the Peter Pan of the solar system.”
Tobias Owen

“It cannot now be predicted whether Europa or Titan will ultimately prove to be the most promising satellite for long-term exploration.”
NRC Decadal Survey of Solar System Exploration, 2003

Titan wants us!

- Low heat load entry; large scale height atmosphere
- Low gravity/high density/cold/high molecular weight environment—optimal for flying
- Benign environment: predictable or learnable winds with low velocity at cruising altitudes (10 km), no radiation, low topography (< 0.5 km; km's in places).
- Radar+DISR is telling us that there are endless evocative vistas to image at 1-10 meter resolution…




Entry
1270 km
Above
Surface
Mach 20
275 km
Peak Deceleration
Heat-Flux Peak
Pilot
Chute
Deployment
Mach 1.5
180 km
Back Cover
Release and
Main Parachute
Deployment
Main
Parachute
Deploys
100 m/s
Descent
140 km
Heat
Shield
Separation
80 m/s
Descent
110 km
Orbiter
EDI Data
to Orbiter
Operational
Scenario
Montgolfiere
Deployment
and Filling
Montgolfiere
Release
5 m/s
Descent
30 km
Montgolfiere
Filled
Side Drift with Winds
2 m/s
Descent
28 km
Montgolfiere
Neutral Buoyancy
2 m/sec
10 km
Data to Orbiter
When in View
Data to Earth
8 km
Surface
Sample
Analysis
1 m/sec
100 m
Tethered
Surface Sample
Target Crater
1 m/sec
100 m
0 m/sec
Neutral
Horizontal
6 km

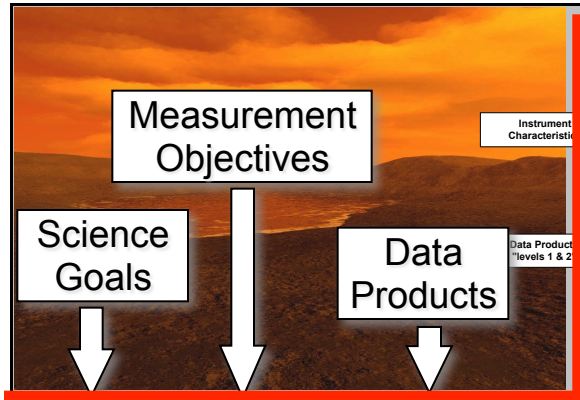
Science Goals and Measurement Objectives of the Titan Prebiotic Explorer (Tipex)

- Determine the origin and evolution of Titan's atmosphere
  - Extent of internal differentiation of Titan's interior
  - Surface evidence for primordial atmospheric composition
  - Differentiation in isotopic ratios between primordial surface constituents and atmospheric constituents

- Determine the cycling of carbon through the interior, surface and atmosphere on all timescales and in all phases
  - Titan methane meteorological cycle
  - Chemical modification of carbon speciation over geological time
  - Sources of methane

- Characterize the prebiotic chemistry that has occurred in the surface and immediate subsurface
  - Extent of chemical evolution of surface organic deposits in geologically active and inactive zones
  - Elemental and mineralogical composition of surface inorganics in contact with organics

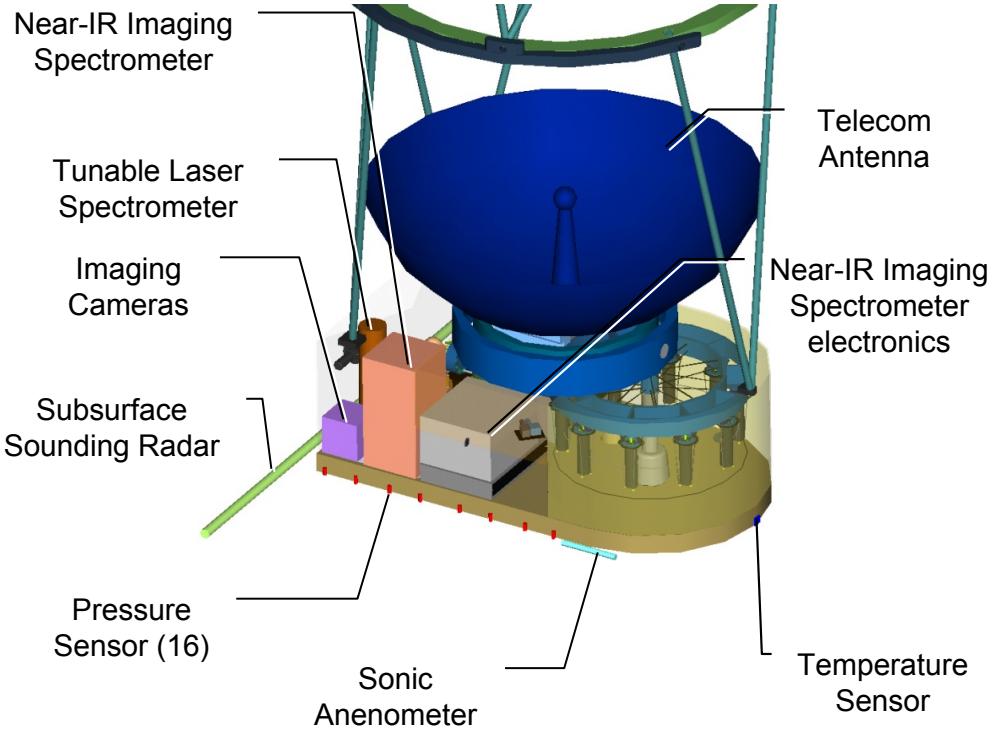
Science Traceability to Instruments



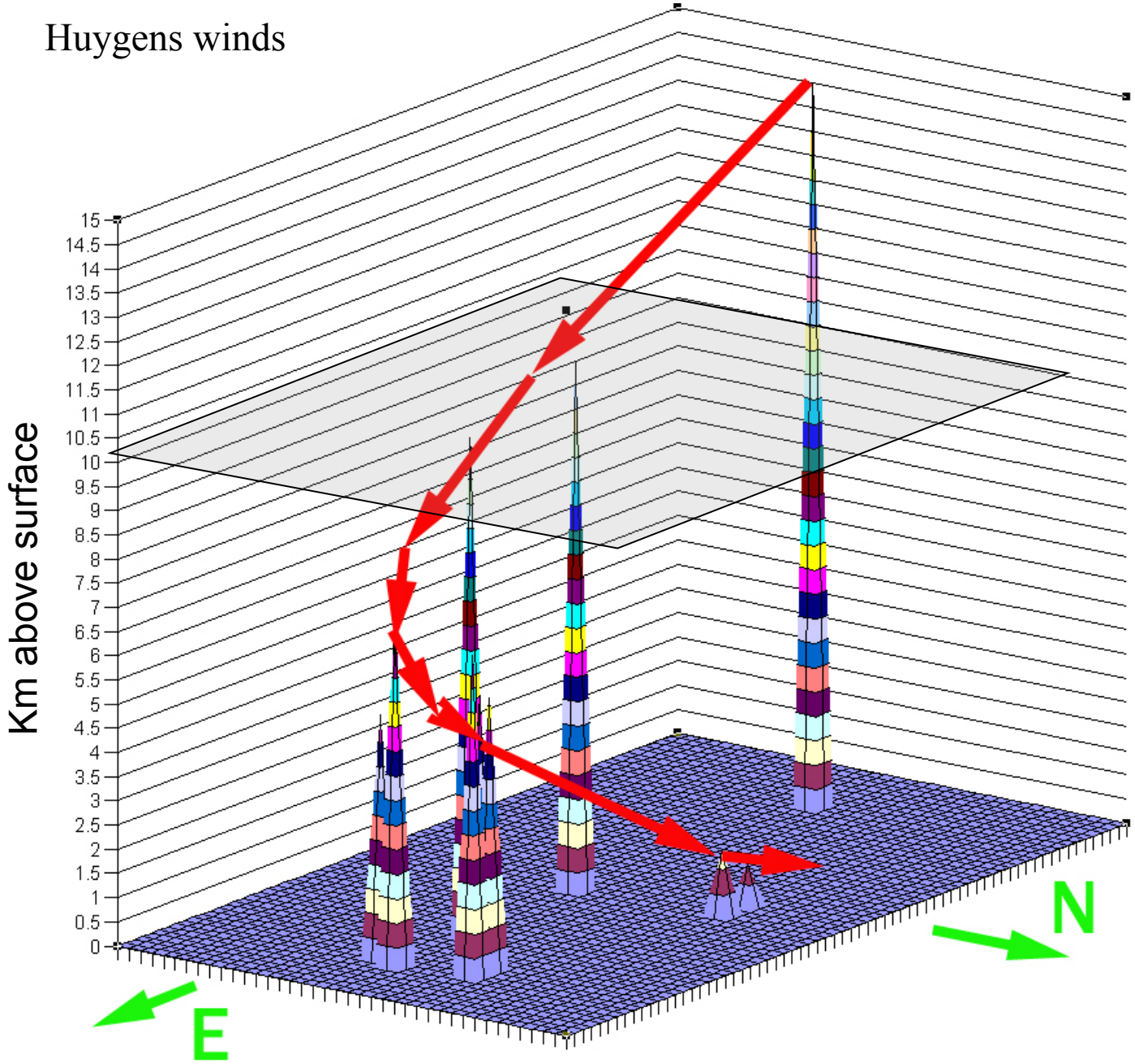
			Orbiter						Aerial Vehicle					Surface Sample		
Science Goals	Measurement objectives	Required measurements ("levels 3 & 4" data products)	Radar Imager/altimeter (Rima)	Near-IR Imaging Spectrometer (NIRIS-O)	Radio Science (RaSci)	Subsurface sounder (SubS)	Near-IR Imaging Spectrometer (NIRIS-A)	Spectrometer (TDLS)	(SoA)	(IC)	Pressure-Temperature Sensor (PTS)	GCMS and Chiral det (GCMS)	det (GCMS)	(AD)	Analyzer (EA)
			λ = TBD (between 0.6-6 cm), TBD m antenna diameter; simultaneous spatial imaging and altimetry	λ =1-5 micron, λ/Δλ= 200; spatial resolution 100 meters	Frequency of TBD, USO of TBD perf on Sonde	Long-wavelength (~10 meters) pulse-sounder system, TBD peak output power, TBD duty cycle	λ =1-5 micron, λ/Δλ= 200; spatial resolution 100 meters, FOV TBD or λ = 0.6-1.5 microns broadband; spatial resolution 1 meter; .Imaging mode 10 cm resolution FOV TBD	TBD wavelength with TBD wavelength range -- see Chris Webster	TBD design. Consider a sonic anemometer for time varying winds, and T. P,T to small errors (0.1 K in T, ?? in P).	Upward and downward looking (+- 60 degrees FOR) stereo imaging cameras; broadband optical/near-IR CCD imager with filters; 10 cm best resolution	500 - 1600 mBar with 0.1 mBar resolution	Neutral & ion species, mass range = 1-600 amus with 5 ppm resolution.	Neutral & ion species, mass range = 1-600 amus with 5 ppm resolution.	Geiger counter	TBD instrument parameters and values
			10% of total surface area mapped at 100 m spatial resolution; altimetric overlays to +/- 10 m	Global spectral hypercubes in 6 selected wavelength bands of interest x 5 channels per band; 400 Gbit data volume with 10x image compression; 100 meters best resolution	Orbit tracking with pulse altimeter geodetic overlays yields 10 meters precision in Orbiter position over time. Sonde location to within 100 meters	Echo Profiles with depths up to several hundred meters with 1m depth resolution.	Spectral hypercubes in 6 selected wavelength bands of interest x 5 channels per band; 400 Gbit data volume with 10x image compression; Imaging data set of 20 km x 20 km survey boxes; data volume 1 Gigabit per box (3 x compression); 1 box per week.	Isotope abundances	Wind velocities with TBD accuracy and precision and cloud maps; P,T over TBD area with temporal resolution TBD	Imaging data set of 20 km x 20 km survey boxes; data volume 1 Gigabit per box (3 x compression); 1 box per week.	Pressure and temperature history	Gas-phase abundances of neutral and ion species with masses between 1 and 600 amus	Abundances of neutral and ion species with masses between 1 and 600 amus	Relative abundance of Carbon 14 -- surface sample	identify elemental composition of surface sample -- surface sample
etermine the origin and evolution of itan's atmosphere	Extent of internal differentiation of Titan interior	Time varying gravitational moments; k2 to an accuracy of 0.001; J2 to an accuracy (absolute) of 10-9. [TBD because the thick atmosphere complicates matters--check with Julie Castillo at JPL as to what is possible.]			X											
	Surface evidence for primordial atmospheric composition	Global distribution of the abundance of ammonia and other "cryovolcanic" compounds on surface with spatial resolution of 10's to 100's of meters. Sensitivity of 0.1%		X			X									
	Differentiation in isotopic ratios between primordial surface constituents and atmospheric constituents	12C/13C and 14N/15N in atmospheric deposits of methane, ethane, HCN, acetylene, ethylene, carbon dioxide, ammonia, nitrogen to an accuracy of 1%						X					X			
		12C/13C and 14N/15N in surface methane, hydrocarbons and nitriles, to an accuracy of 1% .						X					X			
etermine the cycling of carbon rough the interior, surface and tmosphere on all timescales and in ll phases	Titan methane meteorological cycle	Map of fluvial features to meter and decimeter spatial resolution and context with aeolian features over an area of a few hundres square km					X			X						
		TBD cloud particle size distribution, shape and density						X								
		Cloud appearances and disappearences with spatial resolution of 100s of meters		X						X						
		Methane mixing ratio profile at TBD vertical resolution to better than 0.5%														
		Winds measured at TBD frequency of >0.5 Hz							X							
		Temperature profiles to 0.1 degree									X					
	Chemical modification of carbon speciation over geological time	Subsurface structure to depth of several 100 meters with 1m depth resolution over prescribed survey boxes of 100s of square km.				X										
		Molecular composition of the surface at 100s of square meter resolution ; selected sites at 10 meter resolution		X			X									
		Global radar of the horizontal structure of the surface at 100s of square meters spatial resolution coregistered with composition measurements	X													
		Global topography at 100s of square meters spatial resolution and 10 m vertical resolution coregistered with composition and structure measurements	X													
		Images of layering in fluvial deposits at centimeter spatial resolution to a depth of 1-5 m								X						
		Abundances of carbon bearing molecules in gas (100 amu +- 0.2 amu mass accuracy and a resolution of 500 m/delta-m with a sensitivity..... abundance of TBD PPB to accuracy of 10%) and condensed phases (600 amu 0.2 amu mass accuracy and a resolution of 5 PPM with a sensitivity..... abundance of TBD PPB to an accuracy of)										X				
haracterize the prebiotic chemistry at has occurred in the surface and mmediate subsurface	Extent of chemical evolution of surface organic deposits in geologically active and inactive zones	Fluorescence images at spatial resolution of TBD square meters -- may not be achievable at reasonable altitudes due to Titan atmosphere							X							
		Composition of surface organics 600 amu +- 0.2 amu mass accuracy and a mass resolution of 5 PPM with a sensitivity..... abundance of 1 PPB to an accuracy of 10%											X			
		Ages of surface organic deposits with TBD parameters												X		
	Elemental and mineralogical composition of surface inorganics in contact with organics	Morphology of surface sample with TBD mm resolution registered within 10 square centimeter image of the sample site to 1 mm resolution									X					
		Surface sample site characterized over 10 square centimeters at 0.1 mm spatial resolutions								X						
		Abundances of the elements (Li, Na, K, Mg, Ca, Fe, Ni, S, P, F, Cl, Si, B, Al) to > 1ppm to an accuracy of 10%														X

Instruments

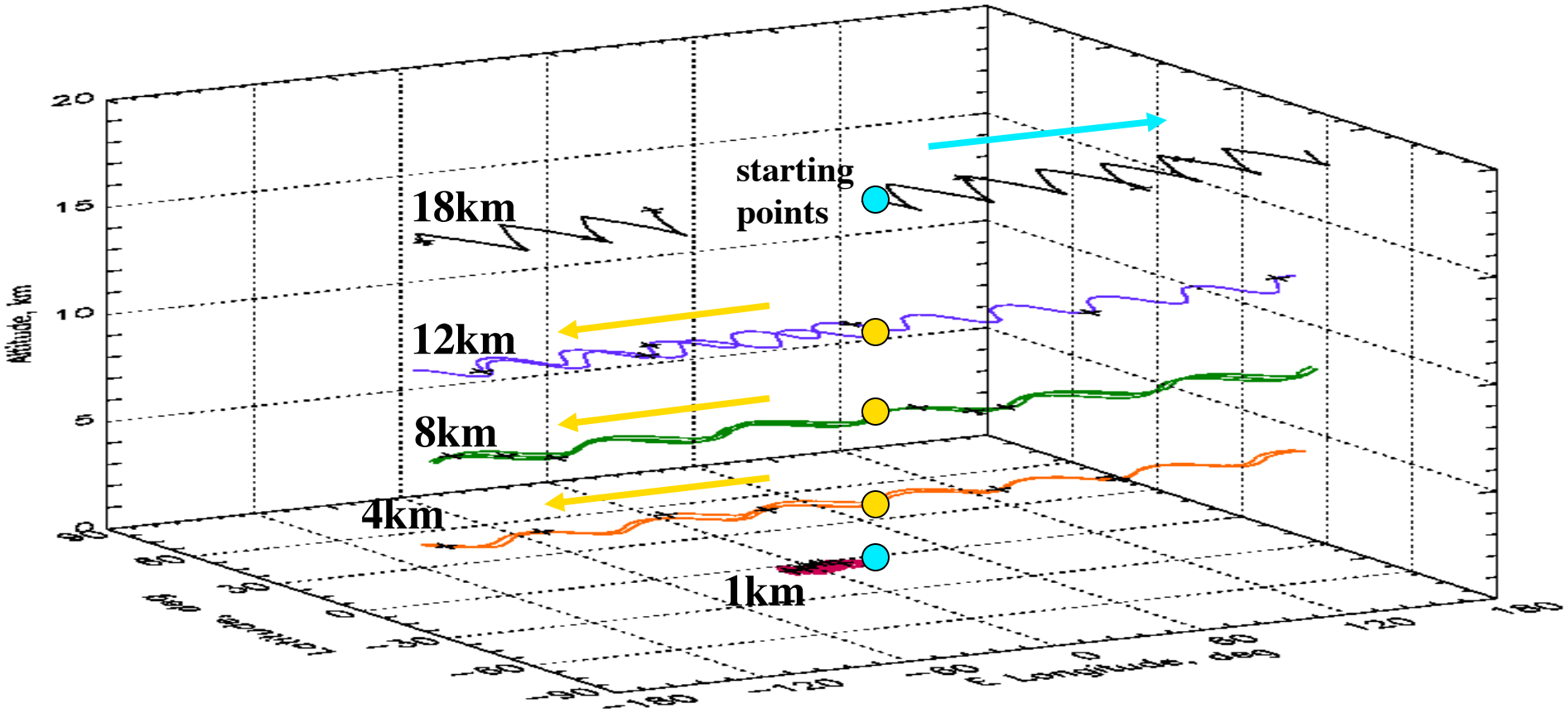
- Gondola
  - Subsurface sounder
  - Near-IR spectrometer
  - Tunable laser
  - Sonic anemometer
  - Imaging camera(s)
  - P-T sensor
  - Gas Chromatograph and Mass Spectrometer
  - Surface Sample Analysis
    - Sample acquisition mechanism
    - GCMS with chiral support
    - Age dating (^{14}C detection)
    - Surface hardness
    - Sample context imager
    - Sample microscope imager
    - Elemental Analysis
- Orbiter
  - Radar imager/altimeter
  - Near-IR imaging spectrometer
  - Radio science



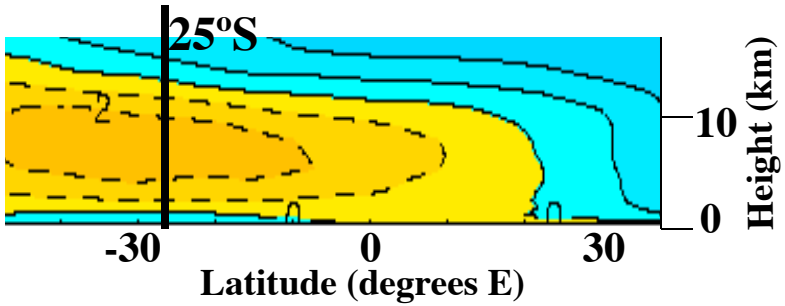
Huygens winds

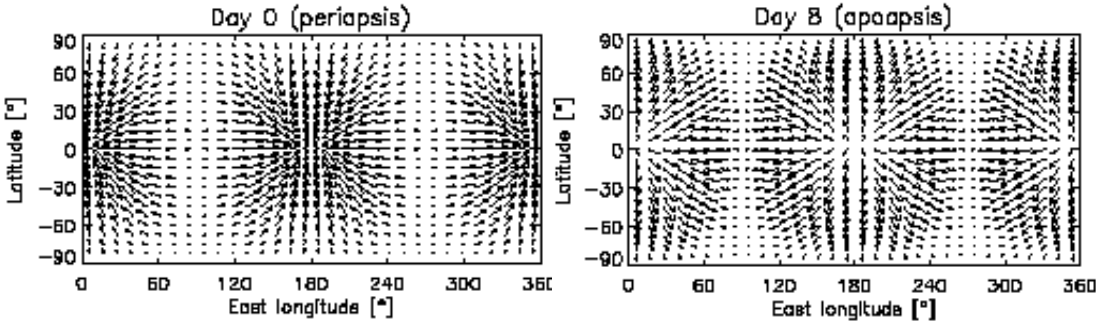


Southern summer (~2032) trajectories for 11 Titan days, starting at 25°S



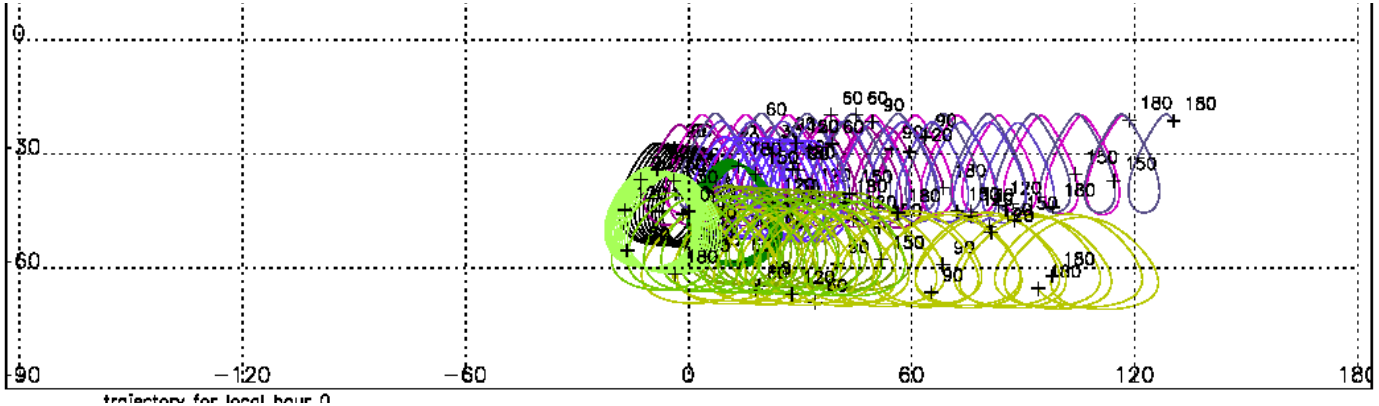
Background zonal winds from Tokano and Neubauer (GRL 2005) + Tidal winds from Tokano and Neubauer (Icarus 2002) => Sample trajectories





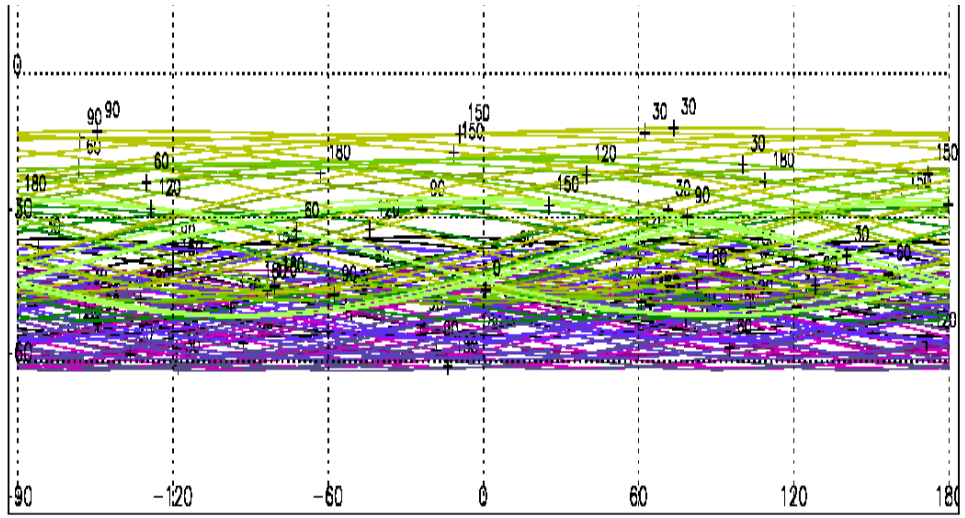
The impact of starting at different local times

Each color is a different local start time (12 total spanning an entire Titan day) - notice how both the amount of wander from the initial location *and/or* the latitudes covered can change significantly

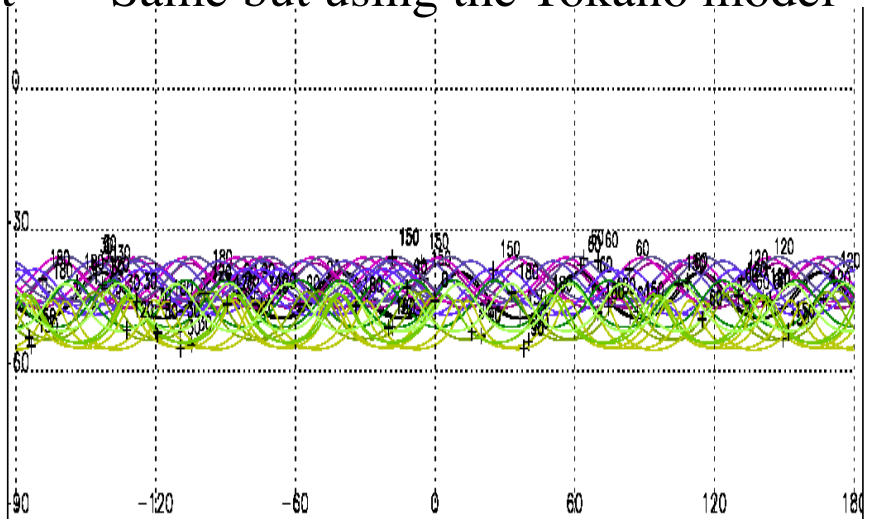


Tokano model, Ls 270, begun at 45S, 18km height

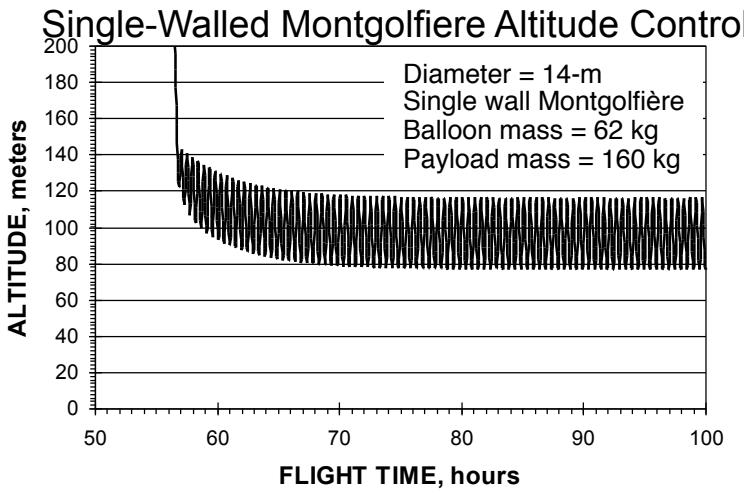
LMD model, Ls 180, begun at 45S, 4km height

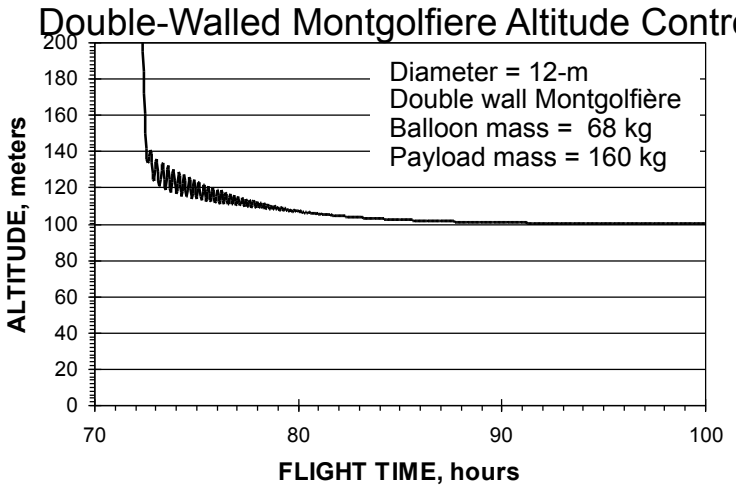


Same but using the Tokano model

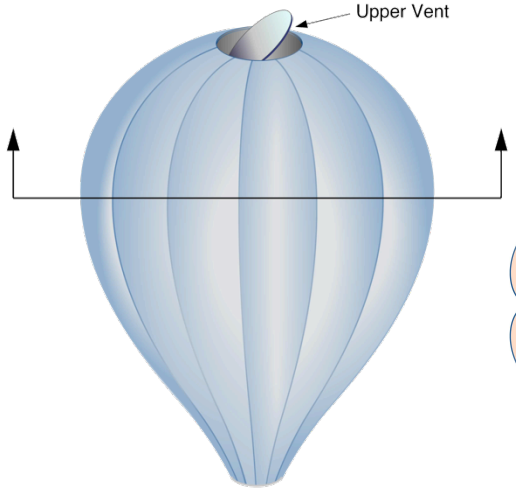


Titan Montgolfière Thermal Analyses

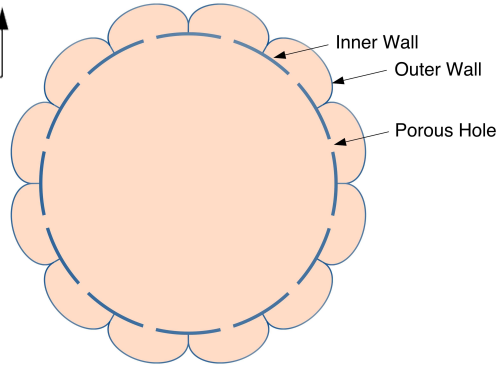




- Both the single-walled and double-walled RPS Montgolfière can function well on Titan.
- Double-walled Montgolfière can hold tighter altitude control and can be smaller (12-m vs. 14-m diameter)
- Double-walled Montgolfière can safely ascend and descend at speeds of 1 km/hr. This corresponds to a 15 degree hazard avoidance angle with surface winds ~1 m/sec



Montgolfiere Front View



Montgolfiere Mid-Cross-Section View

Data Return Capability

- Orbiter
  - Ka-band DTE provides 200 kb/s (power and pointing limited)
  - Occultations 0-35% depending on orbit geometry
  - 1-10 Gb/day
  - Assumes worst case geometry and continuous DSN coverage
    - Edge-on geometry is worst case with 35% occultation
- Aerobot
  - X-band with 1m HGA
  - 2 kb/s DTE
    - Useful for commanding, navigation Doppler, health and status, low rate science for sequencing and dead-reckoning
  - 1 Mb/s relay to orbiter
  - 5 Gb/day average
  - Assumes worst case geometry
    - Low latitude location is worst case with relay contacts 3 days in 8

Technology developments

- Low-T materials
- Adaptive navigation autonomy
- Aerocapture (orbiter)
- Miniaturization for instrument/sampling

International partnering ideas

- Orbiter and balloon US; Gondola ESA
- Orbiter ESA; Balloon/gondola US
- Balloon/gondola US; Enceladus package ESA
- …

To explore strange new worlds….


…will require bold steps…
…and a willingness to ride on the wind.